Chapter 9
Flow-through Raceways

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A raceway in its simplest form is just a flume for carrying water. Raceways for fish culture are tanks that are relatively shallow and rely on a high water flow in proportion to their volume in order to sustain aquatic life. The focus of this chapter is on fish culture systems that pass water through the systems once, provide waste treatment as required, and then discharge the water rather than treat and recirculate it. For successful aquaculture, the inflowing water must be within the temperature tolerance of the species being cultured and should match the optimum temperature for the target species as closely as possible. Oxygen is also provided by the incoming water and is removed by the fish as the water progresses down the raceway. In most raceway systems dissolved oxygen is replenished by allowing the water to fall into subsequent tanks within the raceway. Dissolved metabolites from animals in the system are carried out in the effluent, while settleable particulate wastes can be captured by settling, or less frequently, by other means of filtration. Depending on the water chemistry, the accumulation of ammonia, carbon dioxide, or fine particulates can eventually become limiting to animal production within the system. No natural foods are generated in these systems and nutritionally complete diets are an essential requirement for successful raceway aquaculture.

Aquaculture Production Systems, First Edition. Edited by James Tidwell.

9.1 Types of raceways

9.1.1 Earthen flow-through ponds

In their earliest forms, flow-through systems were created by placing screens or bars above and below a section of stream to confine fish within that area. True raceway production systems in the aquaculture industry evolved from earthen ponds, the most popular shape of which was long and narrow, with sufficient slope to allow for aeration by gravity between ponds if the water was used in more than one pond. Simple earthen flow-through ponds are still in use in many regions today (fig. 9.1), particularly for smaller farms. Earthen ponds have the advantage of being relatively inexpensive to build, but water flow is maintained at low velocities to help minimize erosion. Without supplemental oxygenation, the lower water velocity limits the carrying capacity per unit of water volume (fish density), which in turn reduces overall production. However, because of lower-stocking densities, fish from these systems are reported by producers to be more healthy and colorful in appearance (Hinshaw *et al.* 2004). Earthen raceways are subject to problems with erosion, which is sometimes mitigated using rocks, wood, or concrete structures. Solids management and removal is also difficult due to the irregularity of shapes and surfaces, and a tendency for settling to occur throughout the raceway due to low water velocity. In most instances, solid wastes are left on the bottom to decompose naturally, and then are dredged from the system after several years. Earthen systems also present

Figure 9.1 An earthen flow-through raceway.

Figure 9.2 A series raceway arrangement.

challenges for carrying out other fish management practices such as grading, harvesting, or application of therapeutants.

9.1.2 Concrete raceways and tank arrangements

Raceways can be constructed of wood and prefabricated modular units built of fiberglass are also available. Most modern raceways are constructed of concrete. Compared to earthen systems, concrete raceways can increase production 25 to 40% using the same quantity of water (Fornshell 2002). A typical raceway production system consists of a series of tanks, usually rectangular with water flow along the long axis. On farms, raceways may be divided into two or more tanks at each step in the series, but on smaller farms the tanks are usually in pairs for ease of access (fig. 9.2). Larger farms may construct access on the tanks and have multiple raceways in parallel series (fig. 9.3). The water in raceway production systems is rarely recirculated, but is nearly always "reused" serially with aeration or oxygenation between tanks.

9.1.3 Advantages of raceways

Compared to ponds, which are also semi-closed production systems, raceways have several advantages. Per unit of space, production in raceway systems is much higher. Raceways also offer a much greater ability to observe the fish,

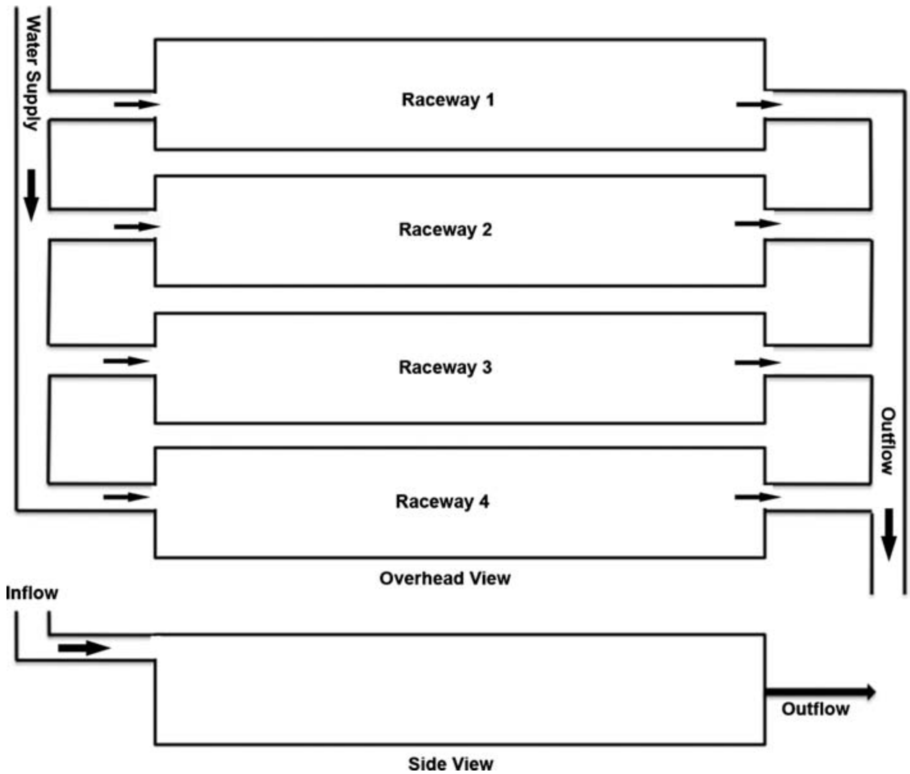

Figure 9.3 A schematic of a parallel raceways system.

making feeding potentially more efficient and disease problems easier to detect and at earlier stages. If disease signs are observed, disease treatments in raceways are easier to apply and require a lesser amount of chemicals than a similar number of fish in a pond (due to the higher fish density in the raceway). Raceways also allow closer monitoring of growth and mortality and better inventory estimates than ponds. Management inputs such as size grading are much more practicable in raceways than they are in ponds, and harvesting is also easier.

9.1.4 Limitations of raceways

The disadvantages of raceways are primarily related to their need for a large, consistent flow of high-quality water. Since such resources are not common, locating and securing a proper water supply is a major consideration. Also, commercial viability often requires that the water flows by gravity through multiple tanks or raceways before it is released. This adds a requirement for an elevation of the water source and suitable topography for the gravity flow between tanks. Another limitation compared to ponds is the release of a high volume of effluent containing low concentrations of metabolites. While ponds

largely process fish wastes within the culture systems, raceways, with their low retention times, do not.

9.2 Physical requirements

9.2.1 Site characteristics

Most raceway production systems are found where three criteria can be satisfied: (1) an inexpensive and reliable supply of flowing water is available; (2) sufficient slope is available or can be created to allow gravity flow of water through and away from the system; and (3) a culture species of sufficient value and tolerance to high density to be grown. These requirements can be satisfied by careful site selection, by capturing an artesian water source such as a spring or well, or by diverting water from a natural water body such as a river or the outflow from a lake. Due to the cost of pumping and the need for redundancy in pumps and power supplies, water sources that can provide flow to the raceways using gravity flow are preferred and often dictate the specific farm location. Locations with geologic features conducive to formation of springs such as the Thousand Springs area of the Snake River Canyon in Idaho are well suited to raceway aquaculture development. Regions such as the north slope of the Central Anatolian plateau of Turkey or the Appalachian Mountains of eastern United States have numerous rivers and streams with protected water sources that also are suitable for raceway aquaculture. Farms based on diverted surface waters tend to be smaller in scale than the spring-fed systems in the Snake River Canyon area, due to limitations on water withdrawal, availability of sites with suitable slope and proximity to the water supply, and variations in seasonal water flow. Raceway systems using saltwater are nearly non-existent as saltwater springs or streams are also nearly nonexistent.

9.2.2 Raceway characteristics and arrangements

Individual raceways are long, narrow, shallow troughs, typically divided into multiple rearing units. There are several basic designs but a common length to width ratio is 10:1 (Soderberg 1995). To include depth, a ratio of 30:3:1 is recommended (lenth:width:depth; Hinshaw *et al.* 2004). Common sizes of individual units are 7- to 9-m long by 3- to 5-m wide by 1.1-m deep (Mazik & Parker 2001). These individual units are grouped together in different arrangements based on water flows, elevation of water source, and topography.

9.2.3 Parallel raceway systems

In a parallel arrangement (fig. 9.3) multiple raceways are grouped in such a way that they all receive water from the same source. It makes one pass through each

raceway then the flows are combined into a common outflow. The advantage to this arrangement is that each unit operates independently. The potential for disease transmission from unit to unit is greatly reduced. Also, the water quality in each unit is not affected by the tank location in the farm, as the units do not receive water from, or release water into, other production units (Landau 1992).

9.2.4 Serial reuse raceway systems

To maximize production per unit of water flow, another design is to arrange the individual units in a step arrangement that allows water exiting the distal end of a raceway to drop down and enter the proximal end of the next (fig. 9.2). Since oxygen is the first limiting factor in production intensification in flow-through raceways (Colt *et al.* 2009), the drop from one raceway into the next is used to re-aerate the water. To accomplish this, the system is designed with a 0.6 m drop between sequential raceways (Mazik & Parker 2001). Several devices have been developed and tested for increasing oxygen transfer over a gravity fall, including splash boards, stair steps, and cascades (Soderberg 1995). The drop from one raceway to the next replaces approximately 50% of the oxygen consumed by fish in the previous section (Mazik & Parker 2001), depending upon the height of the fall and other factors. The oxygen content of the incoming water combined with this gravity aeration between raceways accounts for nearly all the oxygen budget of a serial reuse raceway system.

To increase production, some producers also add mechanical aeration or oxygenation, especially during peak feeding periods. However, aeration or oxygenation can add significantly to the cost of production. Once oxygen needs are satisfied, the accumulation of waste products now becomes the next limiting factor in system intensification. Since flow-through raceways are mechanical rather than biological systems, there is no in situ removal or conversion of nitrogenous waste products. If the oxygen removed by the animals' respiration is replaced, the water can continue to be used until the un-ionized ammonia accumulates to harmful levels, approximately 0.03 mg/L as un-ionized ammonia-N.

In the primary trout-producing region of the Hagerman Valley of Idaho in the United States, the water can be sequentially used in four to five raceways before un-ionized ammonia concentrations become too high (Fornshell 2002). In contrast, the waters of trout producing areas of the southern Appalachian Mountains such as North Carolina are soft (poorly buffered) and slightly acidic in pH. This ionized form of ammonia is less toxic to the fish. Therefore, higher levels of total ammonia can be tolerated, which equates to more water reuses before ammonia becomes limiting. Up to twenty reuses are possible in these regions if oxygen demands are met (Fornshell 2002) and provisions are made to remove carbon dioxide. Usually stocking rates are reduced in downstream raceways due to decreasing water quality and accumulated metabolites. If there is sufficient flow, multiple serial reuse raceways can be built side by side. The

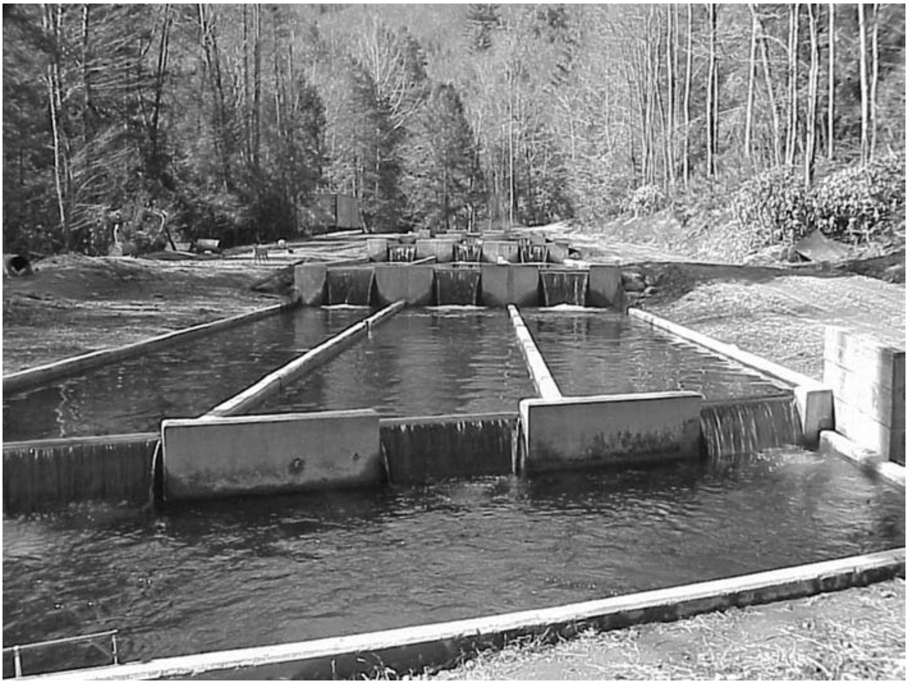

Figure 9.4 A series raceways arrangement illustrating the tiers of raceways at each level.

raceways at each elevation or step are known as a tier (Mazik & Parker 2001). Raceways at each level share walls to reduce construction cost (fig. 9.4).

9.3 Water requirements

9.3.1 Required flows

Since flow-through raceways rely on inflowing water to supply oxygen and water leaving the system to remove ammonia, the amount of water available and its physical/chemical characteristics are the primary factors determining the production capacity of each system. As stated previously, water resources of a commercial scale are hard to locate and dictate where flow-through raceway aquaculture systems can be located. Minimum water flows of 5,678 to 7,570 liter per minute (Lpm) are needed to efficiently operate aquaculture raceways with the typical dimensions described previously (unit volumes of 21 to 45 m^3; Mazik & Parker 2001). Smaller production systems can operate efficiently using smaller water supplies but production will also be proportionally lower. These flow rates should represent at least four water exchanges ("turnovers") for each unit per hour (Fornshell 2002) and up to nine turnovers per hour (Soderberg 1995). If there are multiple production units in series, each tier will require this much

flow. If there is a seasonal variation in flow, projected production should be based on the lower flow season.

9.3.2 Water sources

Water quality and quantity are the primary determinates of the carrying capacity of raceway systems. Important water quality variables include not only oxygen content, alkalinity, hardness, and pH, but also suspended solids and temperature. Surface waters are used in many regions, especially in locations that receive regular heavy rainfall (Soderberg 1995). Water temperatures can vary seasonally, as can flow rates. For trout culture in the United States, requiring water temperatures of 10 to 15°C, surface waters in the southern Appalachian region are considered suitable at high elevations (>900 m). Below this elevation water temperatures can become high enough in summer to reduce survival and low enough in winter to slow growth (Soderberg 1995). When available, ground water sources are preferable to surface waters, as they tend to have more stable temperatures and reduced risk of contamination from wild fish or pathogens (Hinshaw *et al.* 2004). Ground water temperatures are almost constant throughout the year. The temperature of a region's ground water can be estimated from the annual mean air temperature of the region (Soderberg 1995), unless influenced by geothermal activity. The negative aspects of groundwater sources are that they can be low in some gases (such as oxygen) and high in others (such as carbon dioxide, nitrogen, or hydrogen sulfide; Hinshaw 2000). This is especially true if the water has been confined within impermeable geologic strata. Another negative is that where ground waters emerge as springs, they tend to be at low elevations, which do not allow the gravity flow required for efficient serial reuse.

Another source of ground water has been under evaluation in recent years. In the coalfields of the Appalachian region of the eastern United States, there are hundreds of deep mines that have been abandoned. After mining ceases, these mines usually fill up with ground water and even overflow. This represents a significant source of readily accessible ground water, which can often be used without pumping, either through gravity flow or siphon. Initially, there were concerns about low pH (acid waters) or the potential of heavy metals. However, in sites that have not been actively mined for decades, these do not seem to be significant issues. It appears that these groundwater resources represent a largely untapped economic resource for a region in dire need of economic opportunities (D'Souza *et al.* 2004).

9.4 Carrying capacity

9.4.1 Indices of carrying capacity

A number of methods have been developed to estimate carrying capacity of flow-through raceway systems. To date, most of these models have been based

on metabolic characteristics of rainbow trout (Haskell 1955; Willoughby 1968; Piper *et al.* 1982), the species most commonly associated with raceway systems. The carrying capacity of each tank in a raceway system is dependent on several factors including water flow, tank volume, exchange rate, water temperature, oxygen content, pH, fish species and size, production targets (feeding rates), and accumulation of waste products. Piper *et al.* (1982) recommend using flow and density indices to calculate carrying capacity in flow-through systems. Both indices are important to know as spatial requirements and water requirements of fish have been found to be independent (Soderberg 1995).

9.4.2 Flow index

The flow index (an index of weight of fish per unit fish size and water flow) is calculated as follows: $F = W/(L*I)$, where F = flow index, W = known permissible weight of fish, L = length of fish, and I = water flow in units of volume per minute. Standard flow index tables are available that have calculated the flow index at various temperatures and elevations with the assumption the incoming water is at or near 100% saturation with atmospheric oxygen levels. By rearranging the formula to: $W = F*L*I$, the permissible weight can be calculated. The total fish biomass per unit water flow in a tank is referred to as the tank “loading.”

9.4.3 Density index

The density index calculates the maximum allowable weight of fish per unit of tank volume. The level of density that aquatic organisms will tolerate is affected by behavioral aspects of the species, as well as their physical and/or physiological traits (Soderberg 1995). Too much crowding can cause behavioral problems, physical problems, or increased disease and disease transmission, even if water quality conditions are adequately maintained. The density index is calculated as: $W = D*V*L$, where W = permissible weight of fish, D = density index, V = tank volume, and L = fish length. Annual production or yield is generally two to three times the total farm carrying capacity.

9.4.4 Estimating carrying capacity

The flow and density indices were developed at state and federal hatcheries where production goals differ from commercial facilities and are conservative relative to maximum potential carrying capacity. Many commercial aquaculturists base their carrying capacity on empirical observations relative to available oxygen, where a predetermined limit of dissolved oxygen flowing out of one unit in a raceway into the next unit is established. For example, incoming water to the

Text Box 9.1 Calculations of Optimum Loading Capacity

Assume an aquaculture facility with two raceways in series. Total flow to the facility is 28.32 Lps (1 cfs). Incoming DO level is 9.0 mg/L. Desired levels are 7.0 mg/L at the effluent of raceway 1 and 6.0 mg/L at the bottom of raceway 2. Average oxygen recharge is 0.7 mg/L between raceway 1 and 2. Oxygen-consumption rate is estimated at 200 mg/hr of oxygen per kg fish. Calculate the fish biomass for each raceway that will provide these effluent levels.

Step 1: Determine the available oxygen/hour for each section.

Raceway 1:
(9 mg/L O_2 incoming - 7.0 mg/L O_2 effluent) × 28.32 Lps × 60 s/m × 60 m/hr = 203,904 mg/hr available O_2

Raceway 2:
(7.0 mg/L O_2 incoming - 6 mg/L O_2 effluent + 0.7 mg/L O_2 recharge) × 28.32 Lps × 60 s/m × 60 m/hr = 173,318 mg/hr available O_2

Step 2: Divide available oxygen by oxygen-consumption rate/kg fish. Convert to pounds if necessary.

Raceway 1:
203,904 mg/L O_2/200 mg/hr O_2 consumed/kg fish = 1020 kg of fish carrying capacity

Raceway 2:
173,318 mg/L O_2/200 mg/hr O_2 consumed/kg fish = 867 kg of fish carrying capacity

Note: Oxygen consumption rates vary by species, water temperature, size of fish, and feeding rate. Consumption estimates can easily be generated for specific facilities by monitoring influent and effluent concentrations for known biomass of fish, feed amounts, and water inflow rate over a period of time or may be found in the literature.

Colt and Orwicz (1991) also describe methods for calculating carrying capacity in culture systems where oxygen is not a limitation, such as when pure oxygen is added in flow-through raceway system.

first unit is at 100% oxygen saturation and the predetermined limit of outgoing water is set at 70% of saturation. The available oxygen is calculated based on the water flow and the incoming concentration of dissolved oxygen. The allowable biomass is calculated by dividing the available oxygen by the metabolic oxygen consumption of the fish. An example of this method is given in text box 9.1.

Table 9.1 Facilities characterization of five model systems.

Facilities	1	2	3	4	5
Raceway flow (Lpm)	946	6,000	5,400	10,000	10,200
Farm flow (m^3/s)	0.09	0.97	3.2	2.7	8.5
Load (kg/Lpm)	1.6	4.3	1.4	1.8	1.5
Fish density (kg/m^3)	38	27	32	51	37
Production (kg/Lpm) (5.34)	4.25	7.81	5.32	6.73	6.23
Water use (m^3/kg) (98)	123	67.4	98.8	78.2	84
Annual production capacity (MT)	23	454	1,021	1,089	3,175

Notes: Facility characterization from True *et al.* (2004); numbers in parentheses represent industry averages.

9.4.5 Production

Much of the commercial aquaculture industry that is raceway-based still operates within the range of productivity outlined by Westers and Pratt (1977), normally carrying between 20 and 80 kg of fish per cubic meter of water volume (approximately 2 to 5 pounds per cubic foot) with water exchange rates per tank of three to six times per hour. The water is reused serially four to six times or until ammonia becomes limiting—then it is discharged. For example, in the major trout producing region of the United States (Idaho), the carrying capacity for trout averages 1.8 kg/Lpm of water flow at densities of 27 to 51 kg/m^3 (table 9.1). Annual production per unit averages 5.3 kg/Lpm of flow (cumulative of multiple crops). When all of the raceways in a series are combined, production may reach 9.66 kg/Lpm of flow (Brannon & Klontz 1989). In areas where the waters are slightly acidic, ten or more uses are typical and other factors such as carbon dioxide or suspended solids may become limiting before ammonia. In a region with lower pH water, such as the southern Appalachian Mountains in the United States, production has reached as high as 17.2 kg/Lpm of water flow (Hinshaw *et al.* 2004, trout yield verification study; unpublished data).

These indices are useful tools to be used in production planning for stocking into and production rates out of most raceway production systems. If properly designed with sufficient water exchange (four to six turnovers per hour) the estimates of carrying capacity obtained from the Flow Index and Density Index should be nearly equal (Hinshaw 2000). For systems that add pure oxygen, the Flow Index is typically higher and other factors other than oxygen will limit production, such as an accumulation of carbon dioxide from the fish. The farm's oxygenation and aeration systems should be designed to also remove carbon dioxide from the water for efficient production.

9.5 Water consumption and waste management

9.5.1 Water budgets

In comparison with ponds, water budgets for flow-through aquaculture systems are simple. The budget is controlled by a regulated water inflow, and the outflow

rate equals the inflow rate. The water is retained in the system for only a matter of minutes or hours. Rainfall contributions and evaporation losses are negligible. Flow-through systems do not allow runoff to directly enter the rearing units in an uncontrolled fashion. Farms that rely on surface waters use waters only from protected or underdeveloped watersheds. Most raceways are constructed of impermeable materials so seepage into or out of the system does not occur. Water flows per raceway vary in proportion to raceway size, fish density, and fish metabolic needs as previously described. In practice, water flow rates per raceway are based on desired water exchange rates and, to a lesser extent, water velocity. For example, a 3-m-wide raceway will typically receive 85 to 100 Lps.

Flow-through aquaculture systems are a nonconsumptive use of water. Since evaporation and other water losses from tanks are minimal, the only regular removal of water is in the form of harvested fish or in the removal of fish wastes. Goldburg and Triplett (1997) mischaracterized water use in the Idaho trout industry as consumptive by implying that aquaculture was responsible for declines in groundwater levels in the Eastern Snake Plain Aquifer. In reality, naturally occurring flows are temporarily diverted through production units and are then returned to the receiving stream with little or no actual loss of water.

Although water is not consumed during use, flow-through systems do require the use of large volumes of water per unit of fish production compared to other aquaculture production systems. For example, raceway production of trout in the United States uses 98 m^3 of water per kg of fish produced compared to 1.25 to 1.75 m^3/kg for channel catfish in undrained levee ponds and 6.5 to 10 m^3/kg for channel catfish in watershed ponds (Hargreaves *et al.* 2002). While the classic concept of water conservation is meaningless in flow-through aquaculture systems (Hargreaves *et al.* 2002), their water use efficiency can be improved by using technologies that increase fish production per unit of water flow. Examples of such technologies include rigorous water quality management, high-quality feeds, and using improved fish stocks.

9.5.2 Management of solids

As flow-through systems, raceway-based farms do not retain water long enough for significant biological processes to develop for in situ decomposition and solids can accumulate. Most of the solids are from fish fecal matter and uneaten feed (Fornshell & Hinshaw 2008) and if allowed to accumulate for long periods of time, can degrade environmental conditions in the raceway and stress the fish (Cripps & Berghein 2000).

Just as adequate water flow is important to fish growth, it is also important to solids management. Raceways are designed to promote "plug flow," which is equal water velocity in all parts of the water column. Westers (2001) reported that for a raceway to be self-cleaning, it needs a water velocity of 10 cm/s. However, this rate is higher than can normally be achieved in raceways on a

Table 9.2 Water flow rates for raceways of various dimensions needed to achieve a water velocity of 0.03 m/s (3 cm/s).

Raceway Width (m)	Water Depth (m)	Water Velocity (m/s)	Water Flow Rate (m^3/s)
1.8	0.76	0.03	0.041
3.0	0.76	0.03	0.068
3.7	0.76	0.03	0.084
5.5	0.76	0.03	0.125
5.5	0.91	0.03	0.150

practical basis. A water velocity of 3 cm/s is a good compromise flow rate between efficiently managing fish production and still maintaining self-cleaning characteristics of the raceways. Also, in a production raceway system the swimming action of the fish helps limit settling of solids.

To try to achieve the water velocity of 3 cm/s needed for movement of solids, several modifications have been made in raceway design. Raceways are being constructed that are shorter and narrower to increase water velocities (Fornshell & Hinshaw 2008). Table 9.2 gives a matrix of raceway dimensions and flow rates required to achieve a water velocity of 3 cm/s. Another approach has been to install baffles in the water column to constrict the flow to slots near the bottom. This can increase velocities to 10 to 40 cm/s below the baffles and progressively "sweeps" the solids toward the discharge end (Boersen & Westers 1986).

A number of different methods and technologies have been developed and evaluated for the removal of solids from flow-through systems. However, the majority of treatment options are not suitable for commercial aquaculture because they are either impractical to implement due to interference with other aspects of fish management, too costly, or both (Fornshell & Hinshaw 2008). Currently, sedimentation or settling appears to be the only readily adoptable and cost-effective technology. In some designs, a settling basin receives the full flow and has enough volume to slow the water for solids settling (Fornshell & Hinshaw 2008). In others, solids are settled and collected in quiescent (no fish) zones and then routed to settling basins either next to the raceway (off-line) or at the end of raceway (full flow; fig. 9.5). Stechey and Trudell (1990) recommended having quiescent zones in each raceway. These fish-free zones allow the solids to be concentrated and for off-line settling basins to function while handling less than 2% of total facility flow (Fornshell & Hinshaw 2008).

9.5.3 Settling basins

There are three types of settling basins used in flow-through systems to manage solid waste. They are quiescent zones, full-flowing settling basins, and off-line settling basins. Quiescent zones are screened-off areas below the rearing area at

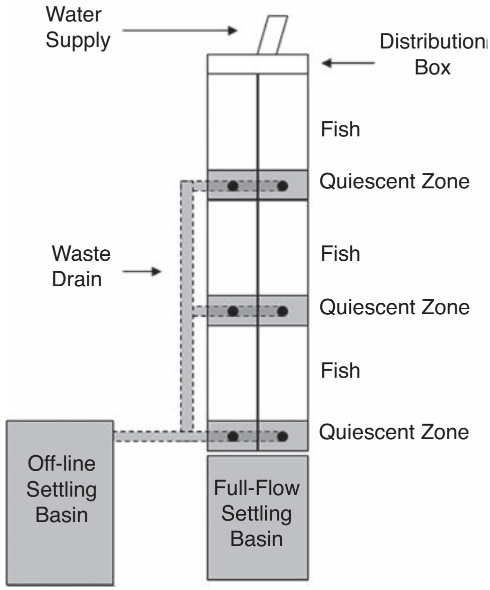

Figure 9.5 A schematic of a solids capture system for raceways utilizing quiescent zones.

the tail end of raceways. The screen, constructed with PVC or aluminum pipe mounted on a wood frame, prohibits fish from entering the quiescent zone. This allows the solids to settle undisturbed. Full-flow settling occurs where the entire flow of a facility passes through a settling basin prior to discharge into receiving waters. Full-flow settling basins are usually used on smaller facilities where total flow rates are less than 283 Lps. Off-line settling basins receive the solids that are removed from quiescent zones. Generally, the combination of quiescent zones in each raceway and off-line settling basins is the most commonly used waste management system to capture and remove solids.

9.6 Feeding and inventory management

9.6.1 Feed quantity and quality

Culture of fish in raceways offers several advantages for farmers in terms of feeding, management of inventory, and harvest. The relatively clear water and high fish densities allow culturists to observe feeding activity and to use a variety of feeding approaches including demand feeders (fig. 9.6). When properly deployed, demand feeders can reduce labor costs, allow all fish access to feed (reducing size variation), and can spread out the oxygen demand on the system caused by feeding activities and digestion (Fornshell & Hinshaw 2008). For rainbow trout in raceways, Klontz (1991) recommended six demand feeders (three per side) in rearing units 3 m wide by 30 m long. Since no natural foods

Figure 9.6 A drained raceway showing proper placement of demand feeders.

are produced within the culture unit, any feeds used in flow-through raceway systems must be nutritionally complete, containing all of the macronutrients and micronutrients required by the animal being cultured.

The relatively clear, shallow water allows fish to be observed for behavior, condition, and for any signs of fish health problems. Mortalities are moved with the water flow and collect at the downstream barrier of the tank, allowing rapid removal. Another advantage of fish production in raceway systems derives from the regular shape of the tanks, which allow fish to be crowded into a small section of the tank (fig. 9.7) for self-grading using bar graders or for harvest using lift nets or fish pumps (fig. 9.8).

9.7 Summary

Flow-through raceways are extremely efficient technologies for producing large volumes of fish in a relatively small area. They are very efficient in terms of labor per unit of fish produced and have attributes that allow for very efficient feed utilization. Costs to build raceway systems generally will be intermediate between the cost of building earthen pond systems and the high capital costs of recirculating culture systems. Due to the requirement for large quantities of high quality water, suitable sites and water supplies for raceway production systems are becoming increasingly hard to identify.

Figure 9.7 Crowding of fish in a raceway to allow grading and/or harvest by pump.

Figure 9.8 Harvesting live rainbow trout by fish pump.

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